51306/WGM/W277

WHAT IS CLAIMED IS:

1. A three-dimensional steering tool for use in drilling a borehole in an underground formation in which an elongated conduit extends from the surface through the borehole and in which the steering tool is mounted on the conduit near a drill bit for drilling the borehole, the steering tool comprising an integrated telemetry section, rotary section and flex section aligned axially along the steering tool for separately controlling inclination and azimuth angles at the drill bit; in which the flex section includes an elongated drive shaft coupled to the drill bit and adapted to be rotatably driven for rotating the drill bit, the drive shaft being bendable laterally to define a deflection angle thereof, and a deflection actuator coupled to the drive shaft, the deflection actuator comprising a deflection housing surrounding the drive shaft and having a longitudinal axis and an elongated deflection piston movable in the deflection housing for applying a lateral bending force to the drive shaft for making changes in the deflection angle of the drive shaft and which is transmitted to the drill bit as an inclination angle steering adjustment; in which the rotary section is coupled to the actuator and includes a rotator actuator for transmitting a rotational force to the deflection actuator to rotate the deflection piston to thereby change the rotational angle at which the lateral bending force is applied to the drive shaft which is transmitted to the drill bit as an azimuth angle steering adjustment; and in which the telemetry section measures the inclination angle and the azimuth angle during drilling and compares them with desired inclination and azimuth angle information to produce inclination control signals for operating the deflection actuator to make steering adjustments in the inclination angle and for separately

producing azimuth control signals for operating the rotator actuator for making steering adjustments in the azimuth angle.

2. Apparatus according to claim 1 in which the conduit is an elongated rotary drill string.

3. Apparatus according to claim 1 in which the deflection actuator comprises an elongated deflection housing surrounding the drive shaft, and an elongated hydraulically operated piston in the deflection housing for applying the bending force distributed lengthwise along the drive shaft for flexing the drive shaft laterally to produce said deflection angle thereof to thereby change the inclination angle at the drill bit.

4. Apparatus according to claim 3 in which the rotator actuator is coupled to the deflection housing and includes a rotator piston movable in proportion to a desired change in the azimuth angle and a helical gear arrangement on the deflection housing coupled to the rotator piston and rotatable in response to piston travel to rotate the deflection housing to change the azimuth angle at the drill bit.

5. Apparatus according to claim 1 in which the hydraulically powered bending force is applied to the deflection piston by drilling mud taken from an annulus between the conduit and the borehole.

6. Apparatus according to claim 1 in which the deflection actuator applies the bending force to the drive shaft while the rotary actuator applies the rotational force to the deflection actuator for making simultaneous adjustments in the inclination angles and the azimuth angles.

7. Apparatus according to claim 1 in which the feedback loop comprises a closed loop controller including a comparator for receiving the measured and desired inclination angle and azimuth angle command signals for producing inclination and azimuth error signals for making the steering adjustments.

8. Apparatus according to claim 1 in which the telemetry section comprises an onboard mud pulse telemetry section for receiving the desired inclination and azimuth angle input signals and utilizing mud pulse controls for operating the deflection actuator and the rotator actuator from drilling mud taken from an annulus between the conduit and the borehole.

9. The apparatus according to claim 8 in which the mud pulse telemetry section provides open loop control to the deflection actuator and the rotator actuator, and in which electrical controls provide closed loop control to the actuators.

10. Apparatus according to claim 1 in which the deflection actuator includes axially spaced-apart end bearings for mounting the drive shaft along a longitudinal axis of the steering tool, and a deflection piston for applying the lateral bending force to the drive shaft between the end bearings to bend the drive shaft while the end bearings constrain the drive shaft on opposite sides of the deflection piston.

11. Apparatus according to claim 1 in which the deflection piston contained in the deflection housing is positioned on one side of the drive shaft and the drive shaft has a longitudinal axis aligned with a longitudinal axis of

the deflection housing, and the lateral bending force is applied by the piston as a unitary force which physically bends the drive shaft to deflect its longitudinal axis away from the axis of the deflection housing.